

# Automation & Control Remote Laboratory: Evaluating a Cooperative Methodology

F. Soares<sup>1</sup>, C.P. Leão<sup>1</sup>, V. Carvalho<sup>1</sup>, R.M. Vasconcelos<sup>2</sup> and S. Costa<sup>1</sup>  
(<sup>1</sup>R&D Algoritmi Centre, <sup>2</sup>R&D 2C2T), University of Minho, Guimarães, Portugal  
fsoares@dei.uminho.pt

**Abstract**—This paper presents a study carried out in order to evaluate the students' perception in the development and use of remote Control and Automation education kits developed by two Universities. Three projects, based on real world environments, were implemented, being local and remotely operated. Students implemented the kits using the theoretical and practical knowledge, being the teachers a catalyst in the learning process. When kits were operational, end-user students got acquainted to the kits in the course curricula units. It is the author's believe that successful results were achieved not only in the learning progress on the Automation and Control fields (hard skills) but also on the development of the students soft skills, leading to encouraging and rewarding goals, motivating their future decisions and promoting synergies in their work. The design of learning experimental kits by students, under teacher supervision, for future use in course curricula by end-user students is an advantageous and rewarding experience.

## I. INTRODUCTION

The demanding of great compatibility and comparability between higher education systems, regarding students mobility and the adoption of new learning and teaching methodologies, changes the European Higher Education politics. Apart from the process of course harmonization [1] and the translating of student's workload in European Credit Transfer and Accumulation System (ECTS), the Bologna declaration was also the beginning of a new paradigm: the student is the responsible for his own learning process education, acquiring not only technical competencies but also skills needed for his personal development.

Among the challenges brought by new teaching/learning methodologies, the web-based learning environments help students and teachers' engagement in the knowledge acquisition process. These web environments cannot be developed only to allow the traditional lectures and exercises support uploading. Several concerns must be taking into account when designing web environments for learning process as it will be the primal factor for gathering students to this learning methodology. So, more innovative and illustrative interactive learning environments must be developed. In the model centered in the student, the main actor in the learning process is the student and the limelight is in the learning process. The teacher must be aware and be prepared for using virtual environments as a complement to the traditional face-to-face lectures.

Another key feature in the teaching learning process is still the learning in the laboratory. Here, the student put into practice the theoretical concepts. The student individually

constructs, manipulates, modifies and controls the experience. This 'learn by doing' is essential to develop good professionals, especially in engineering areas. Hansen [2] states that students' hold back only 25% of that they hear, 45% of that they hear and see and about 70% when they apply the methodology 'to learn by doing'.

Nevertheless, the success of laboratorial classes depends on the organization scheme and financial support. Especially in engineering courses, it is difficult to install and maintain several working places in a laboratory. Often, equipment are expensive, there is not enough laboratorial space and also qualified personnel for supervision and maintenance is not sufficient. This problem becomes highly important if physical and human resources are replicated at each school.

To overcome this problem the remote laboratory concept is used [3]-[7]. With the use of the Internet as a vehicle of knowledge transmission and the availability of the wireless communication in the Universities campus, the Web laboratories are filling this gap, by optimizing material and human resources, space and time.

The idea is to carry out laboratory experiment via the Internet, anytime and anywhere. The students can also have an immediate feedback, allowing them to work in their own space, providing the opportunity to practice when and where they please [8]-[10]. Following the concerns and the choice of the technologies to be used in the development of remote laboratories in the specific areas of Automation and Control education, it is necessary to be aware of some characteristics (technological and/or of pedagogical requirements) [11].

In this paper regarding Automation and Control education [8], different technologies and learning environments are described, in order to develop illustrative and interactive situations, as for example, virtual processes, local and remote laboratories and interactive animations. Students can: a) develop web-animation for an Automation and Control topic; b) design a particular experimental rig for local and remote control; c) practice topics related to an Automation and Control subject using web-based learning environments, previously constructed by other students; d) can solve exercises with real equipment that others have designed and implemented. In all, this is a dynamic learning task: some students actively participate in the development of the learning content and other students simply use and test them. It is regarded as a team work function.

This study explored educational experiences in Automation and Control subjects where students acted as designers and as

final users. The basis of this project is the development of three remote control laboratory kits implemented by the designers' students. These kits were used in Automation and Control lessons as real world examples: developed by students for students' knowledge development. The feedback of both the designer and the end users' students were analyzed. It is the authors believe that the end users students' expectation on this new teaching-learning approach is relevant in the continuity and improvement of this methodology.

## II. TEACHING AND LEARNING METHODOLOGIES

Following the trends on Engineering Education, a multidisciplinary group of teachers from Minho University and from Polytechnic Institute of Cávado and Ave, both in Portugal, work together in designing and implementing new teaching/learning methodologies in Automation and Control Education. Among them, the PLE (Project Led Education), PBL (Problem Based Learning) and the 'Learning by Doing' were methodologies used.

Powell [12] defines PLE as the education focuses on team based student activity relating to learning and to solving large-scale open-ended projects. With the adoption of this methodology [13] the students develop several competencies: Knowledge, Skills and Attitudes. PBL uses real world problems to motivate students to identify and apply research concepts and information by using technology to engage with issues relevant to their future career [14].

Learning by experience engages components from the doing and the thinking. According to Kolb [15], learning from experience has four stages placed in a cycle, as illustrated in Figure 1. The learner can enter at any point in the circle, but the stages must be followed in sequence.

There is a difference between supplying information to the students and providing learning. To give information simply is not enough for an efficient learning. Intuition, imagination, interactivity are considered as key parts in the learning process. In this way, students acquire and develop their knowledge by challenging.

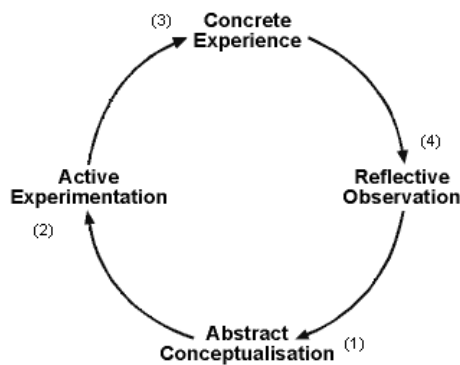


Fig. 1. Experimental learning cycle [15]

Following the previous assumptions, learning by doing was the methodology used in the analyzed experiences that will be

described in the following sections. The four academic teachers involved in the experiences described, came from different scientific background and have different styles. This can be considered as a positive feature since they can emphasize different aspects of the experiential learning cycle in the methods they use. During the semester, regular meetings with the students group were schedule not only to give some theoretical/practical support, but also to enrich reflection and learning in the education process. In the following sections a description of the Automation and Control experiences is shown.

## III. IMPLEMENTED METHODOLOGY

The authors are concerned in developing an Automation & Control remote laboratory that fulfills students' expectations and learning needs. To accomplish these requisites, students can contribute with interesting ideas as they are also the final users of the laboratories. Three different kits were designed and developed in the remote laboratory by engineering students: the "small intelligent" house, the velocity control of a DC motor and the temperature control of a classroom.

The first kit, "small intelligent" house, was designed and implemented by three students from the 4th year of the Industrial Electronics Integrated Master (five years course), under the curricular unit (UC) called Project that lasts for one semester. In this UC, the students have their first contact to the design, study and implementation of engineering problems. In this particular case, the students had no previous knowledge on the Automation and Control subjects needed in the project development; the teacher gave then a brief overview of the related theoretical background (stage 1, Figure 1). Then, the students feel free to, autonomously, start their practical development. The experience runs successfully only with a brief guided automation overview (stages 2 and 3, Figure 1). It obliges students to learn by reflecting on their observations of the real experiment (stage 4, Figure 1), encouraging them in their future decisions and promoting synergies in team work.

The kit, Velocity Control of a DC Motor, was designed and implemented by a final year student of the Industrial Electronics Integrated Master, and was part of his master thesis.

The last kit, Temperature Control of a Classroom, was implemented by a final year student from the Industrial Informatics course (three years course) in the Polytechnic Institute of Cávado and Ave.

It must be pointed out that for these last two kits, the students attended theoretical classes before developing their project work. Although it has been allocated, to each student to develop and assembly, a different kit, students worked in groups integrating a R&D group, developing new skills.

When operational, these kits were used in Automation and Control units as non-compulsory extra class activities (in the Automation UC, on the 3rd year of the Industrial Electronics Integrated Master; and in the Process Control UC, on the 2nd

year of the Industrial Informatics course of the Polytechnic Institute of Cávado and Ave). The learning outcomes are focused on the experimental test of an on-off controller (changing hysteresis value); the use of PID controllers (choosing and testing different digital algorithms, changing controller gains); verify the different control performances; and also, how to implement a “small intelligent” house by using a programmable logic controller.

In order to evaluate the use and the capabilities of this methodology a questionnaire was developed. It allows to understand how students perceived the use of remote labs as well as to understand their difficulties in this process. The feedback obtained from the end user students through questionnaires and qualitative grades allow further improvements.

#### IV. AUTOMATION AND CONTROL LABORATORY

All the kits in the remote laboratory can be accessed under an authorized registration by the web manager. In all, the user monitoring interface was developed in LabVIEW from National Instruments, due to its performance in data acquisition purposes.

##### A. The “small intelligent” house

Virtual, local and remote laboratories and interactive animations are examples of interactive situations to be developed and used as learning environments in Automation and Control subjects.

The main circuit of the “small intelligent” house allows the user to activate and deactivate the maquette (Figure 2). This operation is done by a push button. The sensors were positioned in order to control several characteristics, namely, alarm intrusion, main and internal illumination, main door opening/closing and attic temperature control. The control was implemented by a PLC (CQM1H-CPU61 from Omron <http://www.omron-industrial.com>). The staircase illumination is done by three push buttons placed as follows: the first at the top of the staircase, the second at the middle (half way) and the third at the bottom. For the internal illumination, a motion detector was used and whenever it detects movement, a signal is sent to the PLC, therefore activating the light. If the alarm is switched on there is a light and sound signal whenever the alarm detects an intrusion. The control function activates and deactivates the alarm. The sonorous sound is performed by an independent circuit. The door has a DC motor placed underneath and a light bulb that is switched on when the door is opened or maintained open. The attic temperature control is performed by an Omron temperature controller E5CK.

To control the door, the alarm, the internal and the staircase illumination it was necessary to develop dedicated electronics hardware. This includes various components such as relays that permit the DC motor to invert its rotating direction. To control the alarm circuit a LM555 based timer circuit [16]

was used, thus controlling the pulse every one second obtaining a similar sound as a real alarm (the light bulb enters an intermittent state). The sound generated is obtained by a Buzzer. To control the light bulb of the internal illumination, a motion detector (sensor) was used.



Fig. 2. Set-up of the experiment “small intelligent” house

The simulation of the “small intelligent” house was developed in LabVIEW graphical programming language (<http://www.ni.com/labview/>). This tool was used as it allows building a virtual environment to be applied as an education tool. The LabVIEW interface enables both simulation and “small intelligent” house monitoring and actuation. The direct control is still performed by the PLC. The interface allows also monitoring and testing different proportional, integral and derivative parameters of the attic temperature control algorithm. In simulation run, the sensors and actuators of the “small intelligent” house are replaced by switches and colored signals.

The software developed in LabVIEW also permits the remote control of the “small intelligent” house through the monitoring performed by a Webcam (Trust, 120 Spacecam). This feature was designed to provide to students real-time experiments via the Internet.

##### B. Velocity Control of a DC Motor

Most of the industrial control requirements are still met by proportional-integral-derivative (PID) type controllers [17]. Richalet [18] argued that an impressive majority of problems can be solved by simple PI controllers. Therefore, PID control teaching at undergraduate level is of utmost importance. Computer-aided or web-aided teaching of process control is the answer for teaching continuous and digital control problems in a friendly way.

A remote controlled DC-motor was developed for undergraduate control studies, allowing PID algorithm testing. This system is a supplement to the traditional class teaching, where students can remotely observe how PID control works on the velocity control of a DC motor. The control methodology was implemented in a microcontroller.

Four different digital versions of the PID algorithm are available [19-21]:

**Control Algorithm 1 (position form):**

$$u(k) = Kp.e(k) + Ki.e(k) + i(k-1) + Kd.(e(k) - e(k-1)) \quad (1)$$

where,  $i(k-1)$  is the  $(k-1)$  sum integral,  $Kp$  is the proportional constant,  $Ki = Kp.\Delta t / Ti$  and  $Kd = Kp.Td / \Delta t$ ,  $\Delta t$  is the sampling period,

**Control Algorithm 2 (modified proposed position form I):**

$$u(k) = Kp.e(k) + Ki.\sum_{i=0}^k [e(i) - e(i-1)]/2 + Kd.(e(k) - e(k-1)) \quad (2)$$

**Control Algorithm 3 (modified proposed position form II):**

$$u(k) = Kp.e(k) + Ki.\sum j + i(k-1) + Kd.(e(k) - e(k-1)) \quad (3)$$

where  $j$ , is an unit value that is incremented in the case of a positive error, or decremented, if the error is negative.

**Control Algorithm 4 (velocity form):**

$$u(k) = u(k-1) + Kp(e(k) - e(k-1)) + Ki.e(k) + Kd(e(k) - 2e(k-1) + e(k-2)) \quad (4)$$

A DC Motor from “Maxon RE36” [22] (working at +24 Vdc) is mounted with an encoder “HEDS-5540 A11” [23]. The microcontroller PIC16F876, from Microchip is used to directly control the motor; the control board is linked to the local personal computer by a serial RS-232 communication link for monitoring.

The PID algorithms were programmed in “Assembly” language. The user interface was developed in a LabVIEW environment. Twelve motor velocity reference values can be selected (between 7m/min and 335m/min). The sampling period used is 2 ms. The user must select the PID algorithm to be tested as well as the controller parameters. In order to prevent controller saturation, proportional and integral terms are limited to maximum and minimum values.

A webpage was created in LabVIEW environment using the Web Publishing Tool, enabling the remote access and control of the developed system. An automatic waiting queue is managed by LabVIEW, allowing a single control user. All the facilities available in local control are accessible through the remote interface.

*C. Temperature Control of a Classroom*

The goal of the work is to remotely monitoring and control the temperature of a scale model classroom with reduced

dimensions (36cm width, 34cm length and 31cm height) enabling a high portability and autonomy. It is designed for a resistive temperature sensor with a positive temperature coefficient (PTC) controlled by a PC with custom software developed in LabVIEW using actuators for cooling and warming. It integrates a webcam to observe the activity inside the classroom, as well as the possibility to simulating a temperature disturbance. This scale model can be used to assist educational purposes stimulating students to real world problems.

The overall system software was developed in LabVIEW. To access the SPP, the development tool integrates a specific function (I/O VI). The On-Off control methodology [24] is established according to the setpoint value configured by the user. The monitoring can be performed locally through a 7” touch screen display from Lilliput (<http://www.lilliput.cn/619GL-70NP.html>). To allow remote access it was used the Web Publishing Tool available in LabVIEW, generating a web server with an HTML page, where any device that supports LabVIEW can access using the Internet. The inputs of the developed software application are the disturbance activation button and the setpoint adjustment; the outputs are the Webcam display, the actual and over time temperature values and the input voltage value over time. In order to obtain the acquisition image of the Webcam it was used the LabVIEW Logitech UWA software.

## V. STUDENT’S ATTITUDE EVALUATION

In order to analyze the motivation of the design students, as well as the feedback obtained from the end user students, two questionnaires were developed and their results analyzed. One questionnaire was directed to the designed students and the other to the end-user students.

*A. Design students questionnaire*

The questionnaire “Learn by Doing” was divided in two parts: (1) student characterization and (2) student attitude characterization during the project. Closed questions and a Likert scale were used in order to make a consistency analysis. In the first part, the student identified its personal data: sex, age and year of access to the University. The second part, composed by a set of 12 questions, the student answered the procedural questions describing its attitude during the project development. In particular, it was necessary to understand the students’ perception about the methodology applied in the kits described, in comparison to the traditional education methodology, namely, if it allows an easy comprehension of Automation and Control subjects.

Through the analysis of the questionnaire answers, it was possible to trace the average profile of the students: masculine sex, 23 years of age and 4 registrations at university. All were unanimous in considering that the Internet must be used in the university education level and in believing that “face-to-face” and “virtual” education are complements. The methodology “learn by doing” encourages

the development of work group (67% very and 33% medium). It is confirmed that the involved students had improved, in group, their creativity and responsibility. We must point out that students participated in this project in a voluntary basis.

The methodology presented in this paper allowed students to an easier understanding of Automation and Control. Most of the students had identified that they had applied the knowledge acquired during the project in other curricular units. In a general way, all the students had identified that the relationship teacher/student has a highly important issue. The teachers having conscience of this fact had demonstrated interest revealing availability to the students, presenting new pertinent points of view and encouraging them to state their ideas. At the end, several possible reasons behind the choice of the students to developed this project where listed. The students had identified the acquisition of new knowledge in the interest area allowing qualification for the practice of a job in their areas of expertise (Figure 3) has the most important issues. All the students were unanimous in stating that the projects corresponded to their expectations.

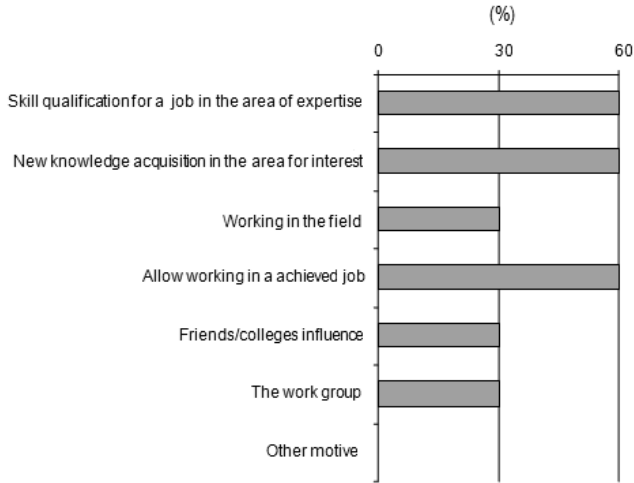


Fig. 3. Answer percentage for each reason listed in the questionnaire that had influence on the project choice

#### B. End-user students questionnaire

The questionnaire to understand and analyze the students' reaction to the use of didactics kits in the teaching and learning in Automation and Control was performed. A group of 34 students responded to the challenge, with an average around 22 years old, 4% were female and 91% 3rd year students.

The questionnaire was divided into 5 main parts: (1) student characterization, (2) work environment identification (operating system and browser identification), (3) didactics kits technical skills, (4) didactics kits motivation and (5) students habits and attitude characterization during the project. Due to the premise of this paper, the set of questions that was analyzed intends to measure the students' degree of concordance concerning their motivation in using the didactics kits as an appropriate tool on their Control and

Automation learning process. The analysis is focused on the average value obtained for the 9 items, evaluated in accordance with the level of agreement: 1 – strongly disagree, 2 – disagree, 3 – undefined opinion, 4 – agree, 5 – completely agree. The student chooses only one option in each item. The items consider were the following:

*Q1: In general, I was motivated for the use of these kits in the course context.*

*Q2: In general, I can say that the performance of the kits...*

*1: ... help me to assimilate the concepts presented during the course semester*

*2: ... made my learning more objective*

*3: ... increases my chances of getting a high final evaluation*

*4: ... motivate me to the course*

*5: ... raise my expectations relatively to the assessment*

*Q3: Running the kits, had nothing to do with my motivation and my interest in this course.*

*Q4: These kits are suitable for my Control/Automation learning process.*

*Q5: I recommend the implementation of these kits and activities, in the next school year, as a teaching/learning tool.*

Figure 4 illustrates the average value obtained for each analyzed item.

The average evaluation was positive (higher than 3) for all the consider items, except for the Q3 item. However, since this sentence was placed in a negative mode, so being less than 3 is a positive perspective.

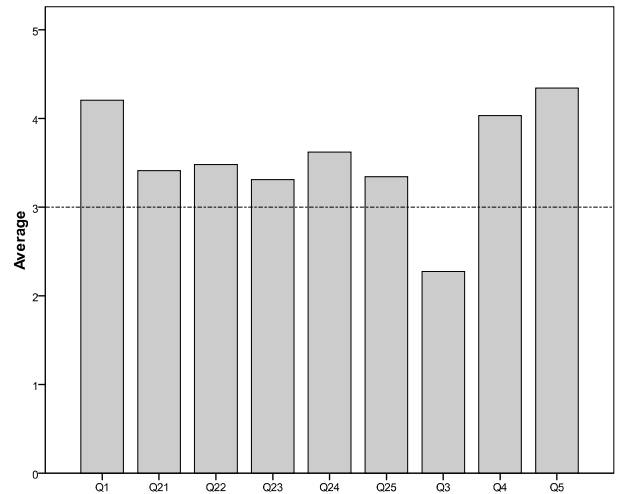


Fig. 4. Average evaluation for didactics kits students' motivation, for each question.

## VI. CONCLUSIONS

In this paper, educational experiences in Automation and Control subjects were described. A group of students

designed and implemented a set of didactic kits based on real environments. These students voluntarily accepted this challenge, being more involved, more committed more openness in their learning process. They implemented three different kits: the “small intelligent” house, the velocity control of a DC motor and the temperature control of a classroom. The graduate students wrote a laboratory handout/manual to help the undergraduate students when they were remotely accessing and testing the projects. Usually, undergraduate students worked in pairs.

Considering the projects evaluation, the students fulfilled all the initial requests. The students’ relationship establishment between the theoretical and practical concerns of the Automation and Control subjects was highly improved. The learning by experience engages components from the doing and the thinking. All the developed kits can be used by other students as a demonstrative tool in Automation and Control classes.

We believe that the paradigm “learn by doing” fortifies the theoretical subjects presented in a class. In this way, students enlarge their knowledge on the particular subject as well as in the creativity development, in the planning capability and in the communication between working groups. Nevertheless, in the methodology based on experiential learning, the responsibility of learning must not be discarded. The experiential learning cycle imposes a powerful structure of its own, like: timetables, deadlines, meetings, running and final reports.

The three developed didactic kits were then introduced as a learning tool in the Digital Control course on the 3rd year of the Industrial Electronics Engineering undergraduate course and in the Process Control course on the 2nd Industrial Informatics undergraduate course. The students’ degree of concordance concerning their motivation in using the didactics kits as an appropriate tool on their Control and Automation learning process, was very positive and must be continued. To follow the students’ opinion, it is authors’ believe to carry on this methodology implementing new kits developed by students for students.

In this work, two institutions cooperate in developing remote laboratories, enabling the optimization of human and physical resources and providing a high level education of excellence.

#### ACKNOWLEDGMENTS

The authors are grateful to the Research Center Algoritmi and WALC research project (PTDC/ESC/68069/2006) for funding. The authors are also grateful to the students that participated in this project as designers and as end users.

This work is funded by FEDER funds through the "Programa Operacional Factores de Competitividade – COMPETE" and by national funds by FCT- Fundação para a Ciência e a Tecnologia, project reference FCOMP-01-0124-FEDER-022674.

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